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PTNSS–2011–SC–136

On the High IMEP Potential of Barrel Engines

Abstract: In this work the possibility of very high performance of barrel engine fueled with gasoline is presented. In this engine several new technologies were used in order to achieve the compression assisted ignition (CAI). The control of CAI combustion reagime was obtained by intesive charge stratification and exhaust gas recirculation (EGR). The additional advantage of barrel engine is its axual symmetry which ensures identical conditions in all cylinders. The application of spherical bearings in barrel engine, instead of classical cylindrical ones, alowed for the increase of permissible loads of crank mechanism. Moreover the noise of engine operation at full load has been reduced due to the untypical kinematics of barrel engine crank mechanism and spherical bearings. All these advantageous features resulted in IMEP level of 2.4 MPa for engine fuelling with homogeneous mixture. The maximum rate of pressure rise was at the same time limited to 0.8 MPa/CAD

Key words: *barrel engine, CAI, downsizing*

Możliwość uzyskania bardzo wysokich osiągów w silniku beczkowym

Streszczenie: W pracy przedstawiono możliwość uzyskania bardzo wysokich osiągów w silniku beczkowym zasilanym benzyną. W silniku tym zastosowano szereg rozwiązań, które pozwoliły na uzyskanie kontrolowanego samozapłonu (ang. Controlled Auto-Ignition – CAI). Opanowanie spalania typu CAI osiągnięto dzięki zastosowaniu silnej stratyfikacji oraz kontroli recyrkulacji spalin (ang. Exhaust Gas Recirculation - EGR). Dodatkową zaletą silnika beczkowego jest osiowa symetria silnika zapewniająca identyczne warunki we wszystkich cylindrach. Zastosowanie łożysk sferycznych, zamiast klasycznych walcowych, w silniku beczkowym pozwoliło na zwiększenie dopuszczalnych obciążeń układu korbowego. Dzięki nietypowej kinematyce silnika beczkowego oraz łożyskom sferycznym uzyskano zmniejszenie hałaśliwości pracy silnika przy pełnych obciążeniach. Zalety silnika beczkowego pozwoliły na uzyskanie średniego ciśnienia indykowanego na poziomie 24 bar, przy zasilaniu silnika mieszanką jednorodną, przy jednoczesnym ograniczeniu maksymalnych przyrostów ciśnienia do 8 bar/CAD.

Słowa kluczowe: *silniki beczkowe, CAI, downsizing*

1. Introduction

Downsizing of internal combustion engines consists in reduction of their capacity with the unchanged same power and torque. This is done by the increase of mass of charge supplied to the cylinder in each cycle by using compressors and air coolers. Decrease of engine size has many advantages:

- Increase of engine efficiency,
- Reduction of engine mass,
- Reduction of number of engine elements – lower production costs.

The level of engine charging can not be increased without penalty. In CI engines the air inlet pressure and compression ratio are limited by the value of maximum pressure after combustion. The limitation of maximum cycle pressure comes from the maximum forces which can be transmitted by crank shaft bearings and in particular by the small end connecting rod bearing. The other constructional constraints are the value of side piston force and friction in this kinematic pair. Therefore, decrease of engine compression ratio is observed with the increase of charging level of CI engines.

In SI engines the allowable charging level is lower because of abnormal combustion may occur before reaching permissible maximum pressure. These abnormal combustion phenomena are:

- Knocking combustion,
- Uncontrolled auto-ignition.

Both phenomena are very unwanted because they are accompanied by large pressure increases which cause very rapid engine damage and generate high noise. Similar problems occur with the change of engine operational regime from SI to HCCI.

In this paper we show how the high mean effective pressure can be obtained in novel barrel engine while keeping the permissible rate of pressure rise not higher than 10 bar/deg. We also demonstrate that in this engine it is possible to operate in CAI mode in the whole operational range.

2. Experimental setup

The studies of CAI ignition mode control at high loads were conducted in the barrel engine Fig.1) designed and constructed at Warsaw University of Technology [1,2]. This is five-cylinder two-stroke engine of 3 dm^3 in capacity with slotted charge exchange system and uniflow cylinder scavenging. Such system gives the most effective way of charge exchange in the engine. Additionally there is possibility of continuous variability of phase timing of inlet and outlet slots opening with the use of very simple mechanism which is not possible to use in the engine with classical crank mechanism.

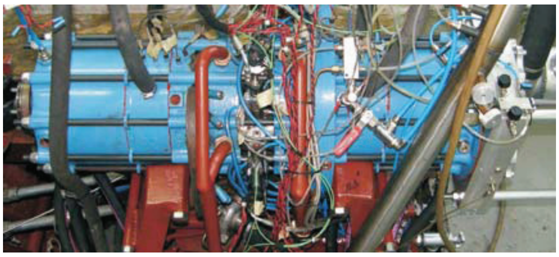

Figure 1. Barrel engine

The unique engine construction allows for the controlled internal exhaust gas recirculation combined with the strong stratification of the charge and therefore it is possible to get local ignition of even very lean fuel-air mixtures. At high engine load the variable charging ratio and internal EGR were used in such a way that the moment of ignition occurred near TDC and the rate of pressure rise dp/dt was limited to 10 bar/deg. Due to the use of CAI in the whole engine operational range, low NO_x emission can be obtained also at high engine loads.

The measurements were performed at the test stand show in Fig.2. The pressure measurements in all five cylinders were done simultaneously with the use of Kistler 6055C80 transducers and the pressure signals were then analyzed by Dewetron data acquisition system.

3. Controlled auto-ignition at high load

The test barrel engine is equipped with direct injection system (DI) of gasoline and gas fuel as well as with the direct injection system of diesel fuel. The fuel can be also delivered to the inlet port (PFI). The studies on autoignition control are in the preliminary stage. We show here only one engine operating point at full load. The tests were conducted with the use of PFI delivery method. The following engine parameters were used:

- Air excess ratio: $\lambda = 1.3$,
- Engine Speer: n = 1500 rev/min,
- Pressure in inlet port: p = 2 bar (abs).

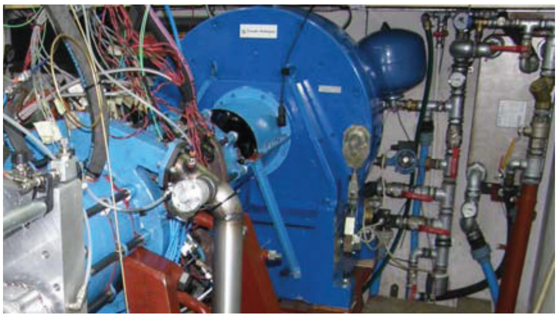

Figure 2. Experimental setup

The engine closed indicating diagram is shown in Fig. 3. It can be observed that besides port fuel delivery and the high pressure exceeding 120 bar no knocking combustion is detected. This effect was achieved thanks to the following engine advantages:

- Lean fuel-air mixture,
- Distributed auto-ignition in the stratified charge,
- Compact combustion chamber giving very short flame propagation distance.

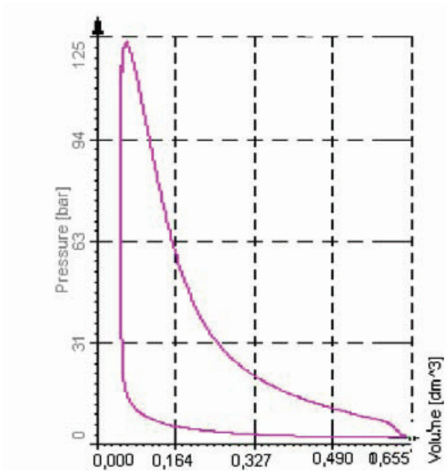

Figure 3. Engine indicating diagram at full load

The cycle work s equal to about 1700 J which gives the mean effective pressure at the level of $p_i = 28$ bar. Such values exist in many large CI engines but they are only in very distant plans of designers of small petrol engines.

Besides such high pressures in the cylinder it was possible to keep the rate of pressure rise at the level of 8 bar/deg (Fig. 4) which is not a large value having in mind low engine speed (1500 rev/min). This result was probably achieved thanks to strong charge stratification which causes that autoignition occurs only in the part of combustion chamber. The rest of the charge burns in the propagating flame. It should be mentioned here that the novel design of the bearing of the small end of connecting rod and the three time lower side piston force than in classical engine, allows for the correct operation of the engine even with the rate of pressure rise equal to about 15 bar/deg.

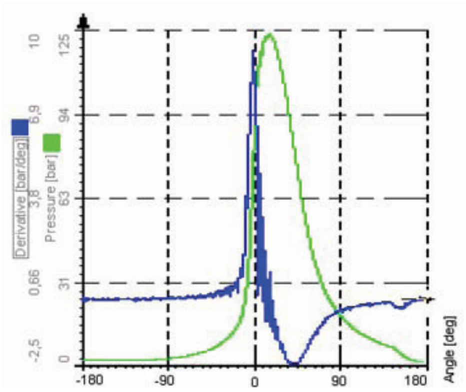

Figure 4. Engine indicating diagram and rate of pressure rise at full load

Figure 5 shows the pressure profiles for the twenty consecutive cycles. It is clearly visible that despite the auto-ignition mode of combustion initiation the pressure variability between cycles is small and equals to about 4 bar. This is due to the fact that auto-ignition occurs simultaneously at many points in contrast to classical single point ignition in SI engines.

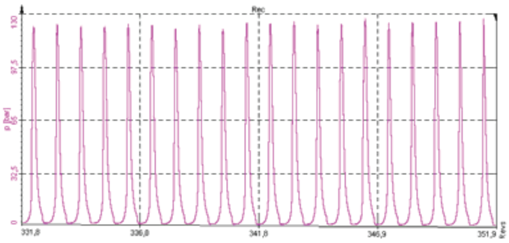

Figure 5. Pressure profiles for 20 consecutive cycles

Conclusions

The problem of control of CAI combustion mode at low engine load has been already successfully solved by researchers and engine designers. However the CAI control at high loads is still a challenge even for the most respective engine research centers and remains their distant goal. The barrel engine presented here operates properly in CAI mode at full load without variable compression ratio (VCR) and electromagnetic valve actuation (EVA) which are used for HCCI system control in classical engines. The main factor of success is the redesign of the old engine concept forgot after invention almost hundred years ago. The same was with the fuel injectors which were invented and used during II World War and then forgotten for the 50 years when the carburetors fully replaced them in a short time. May be the same fate will come for classical crank mechanism?

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